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(54) **Hand controller**

Steuerknüppel

Levier de commande

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(56) References cited:
EP-A- 0 363 739 **US-A- 4 660 828**

Description

Field of the Invention

The present invention pertains to hand controllers according to the preamble of claim 1 and particularly to aircraft hand controllers. More particularly, the invention pertains to displacement aircraft or space vehicle hand controllers.

Related Art

The related art involves conventional hand controllers which rotate about a fixed axis in the base, require movement of both the arm and the wrist, have a high force displacement gradient, and have either no or complex proprioceptive feedback.

In recent years, space and weight constraints in modern aircraft have resulted in compact fly-by-wire or fly-by-light control systems. Such systems reduce the size and weight of flight control hardware in the cockpit. In addition, these systems permit a side-arm controller configuration that reduces obstruction of the instrument panel area directly in front of the pilot. Two general configurations of those compact controllers have been developed--rigid and movable displacement. Rigid controllers measure the force of the control input and have no movement associated with input magnitude. Moveable controllers have a range of motion of about ± 5 cm (± 2 inches) to ± 10 cm (± 4 inches) associated with the magnitude of the control input. The force required to fully displace a moveable controller may be quite small, although the inclusion of a force-displacement gradient has been found to improve control performance.

Difficulties are associated with both types of hand controllers. Rigid controllers may produce severe operator fatigue due to a lack of proprioceptive feedback to tell the pilot how much force he is exerting. That difficulty can be reduced by allowing for a small (i.e., ± 6 mm or ± 1/4 inch) amount of displacement or wobble unrelated to the force-output function. Further, rigid controllers provide fairly imprecise control and suffer from input axis cross-coupling, again due to the poor proprioceptive feedback provided to the operator.

Moveable controllers can provide reasonable control when a fairly heavy-force output gradient (i.e., ≧ 6,8 kg or > ± 15 pounds at full displacement) is used; however, these force requirements result in operator fatigue. At lower force requirements, control imprecision and axis cross-coupling are resulting problems.

Some of these problems were solved upon the conception and development of a moveable hand controller configuration that permits accurate control while requiring a relatively low force-displacement gradient. Also, such hand controller is useful in a side-arm configuration in that it allows the operator's arm to remain essentially motionless in an arm rest while control inputs are made about the fulcrum of the wrist. When the operator provides an input, such hand controller assembly is rotated in an arc having its center at the operator's wrist and/or center is translational. The hand controller also has the advantage of rotation about the operator's wrist joint, thus requiring movement of the wrist only. In other words, that hand controller has a "virtual pivot" that permits inputs to be made about any point in space and the controller translates movement of the controller grip about a point in space (such as the operator's wrist joint) into movements of a sensor about an internal reference point thereby permitting one hand controller to optimally function for all hand sizes. However, that controller has a grip and a sensor platform with a small-displacement and a motion base with spring-loaded legs for flexibility. Such hand controller is disclosed in EP-A1-0 363 739.

Departing from this known hand controller, it is the object of the present invention to further improve it so that it can be matched to different applications. This object is achieved according to the characterizing features of claim 1. Further advantageous embodiments of the improved hand controller may be taken from the dependent claims.

Summary of the Invention

The present invention is still yet a further improvement on the related art. Not only does the present invention have a virtual pivot which accommodates variations in operator action, have six degrees of freedom, and variable pivot point locations; the invention is adaptable for providing various forces and torques and displacements and rotations and provides force feedback which simulates spring-type feedback but having different rates, various stop positions, variable damping, and a variety of reflective conditions to the controller environment including impact, proximity, limits, etc. The system of the invention has a hand controller incorporating system actuators, system sensors and feedback actuators which are connected to system control and force feedback control mechanisms which implement a variable control algorithm. The controller has a hand grip platform which is supported by telescoping legs. Linear actuators drive the telescoping motion in the legs. Motors drive radial angular motion at the universal joints which attach the legs to the base plate. A force/torque sensor is attached to the hand grip platform and monitors control inputs from an operator of the hand controller. There are angular potentiometers, linear potentiometers, and motor tachometers associated with the telescoping legs. The potentiometers provide a measurement of the position and attitude of the platform with respect to the base. Signals from the force/torque sensor, angular potentiometers, linear potentiometers and motor tachometers

are input into the control system. The control system sends signals to the motors to drive the hand controller to the commanded configuration with the appropriate force and feel characteristics at the hand grip.

The virtual pivot of the hand controller system accommodates a wide variety of operator sizes with a "floating" pivot point. Motors and controllers replace springs of the related art hand controller and yet provides force feedback or "feel". Spring rates, spring tension, damping rates, stop positions, the number of control axes, the dimensions and range of control axes, and force reflection characteristics may be programmed with various values based on specific requirements into the control system. The programmability and flexibility of the hand controller system permits the controlling of a large and varied range of devices with a single hand controller. The hand controller system may be programmed to compensate for various gravities, various gravity and inertial effects, or for gravity-free environments. Applications of the hand controller system include use in space stations, space vehicles, helicopters, fixed-wing aircraft, underwater vehicles, robotic vehicles, robotic arm controls, and other applications.

Brief Description of the Drawings

Figure 1 is a drawing of hand controller.

Figure 2 is an overview diagram of the hand controller, control system, and the controlled system.

Figure 3 is a graph showing the relationship of hand grip-applied force/torque versus hand controller movement displacement profiles.

Figure 4 illustrates the vector relationships between base and platform coordinate frames of the virtual pivot hand controller.

Figure 5a and 5b constitute a signal flow diagram of the control system and motor channels.

Description of the Preferred Embodiment

Figure 1 reveals an adaptable six degree of freedom virtual pivot hand controller 10. Virtual pivot hand controller 10 has a hand grip 28 for the operator's input. Hand grip 28 is connected through grip platform 30 to six degree of freedom force and torque sensor 34. Force and torque sensor 34 is an F/T series, model 75/250 sensor from Assurance Technologies, Inc., of Garner, NC 27529. Grip platform 30 is connected to shafts 62 via ball joints 32. Three shafts 62 extend into three linear actuators 36, respectively. Linear actuators 36 cause shafts 62 to extend out of actuators 36 or to withdraw into actuators 36. The amount of shaft 62 extending out of linear actuator 36 is measured by linear potentiometer 38. Linear actuators 36 are driven by motors 40 thereby causing the extension or withdrawal of shafts 62. The withdrawal or extension of shafts 62 via ball joints 32 raise, lower, tilt, rotate and/or laterally move grip platform 30 and hand grip 28. The activity of motors 40 driving linear actuators 36 is monitored by tachometers 42. Linear actuators 36 are attached to universal joints 60, respectively. The other ends of the universal joints 60 opposite of linear actuators 36, are effectively attached to base plate 48. Six potentiometers 44 are, respectively, attached to universal joints 60 for measuring the angles of linear actuators 36 relative to base plate 48. The angle of linear actuator is 36, relative to base plate 48, is driven and set by motors 52 via gear heads 50 and worm and worm wheel assemblies 46. Gear heads 50 are attached to motors 52 through base plate 48 to worms 46. Worms 46 drive worm wheels 46 which are attached to the portions of universal joints 60 that are rigidly attached to linear actuators 36, respectively. Worms 46 driving worm wheels 46 set linear actuators 36 and shafts 62 to particular angles of inclination. Motors 52 are monitored by tachometers 54. Base plate 48 is supported by a surface 58 with structural supports 56. Surface 58 represents the place or area upon which hand controller 10 is situated and mounted.

Figure 2 reveals an overall diagram of the adaptable six degree of freedom virtual pivot hand controller 10 system. Hand controller 10 outputs sensor signals 20 from six degree of freedom force and torque sensor 34, linear potentiometers 38, angular potentiometers 44, motor tachometers 42 and motor tachometers 54. Sensor signals 20 are input to control system 12 which is a processor and specifically a single board microcomputer, as available under the type no. 68020 from Motorola Inc., Schaumburg J11. (USA), having system control 14 and force feedback control 16. Force and torque sensor 34 which is attached to hand grip platform and hand grip monitors the control inputs from the operator. Control system 12, in response to sensor signals 20, sends feedback signals to motors 40 and 52 to drive hand controller 10 in accordance with the commanded configuration, having appropriate force and feel characteristics. The force and feel characteristics are determined by force feedback control 16 and response to sensor signals 20 revealing force, torque, position and rate, and signals from controlled system 18 sensors indicating proximity, force, field dynamics, etc., in response to driving signals 22 to system actuators such as motors, propulsion, etc. Hand controller 10 uses motor biasing to generate the force and feel of springs, damping and mechanical deadbands as illustrated in Figure 3. Figure 3 is a graph of hand grip applied force and torque versus displacement profiles of hand grip 10.

Control interface 22 required to determine hand control 10 orientation and translation in six degrees of freedom contains nine potentiometer measurements (three per leg) that define three position vectors of grip platform 10, corresponding to three fixed ball joints 32, with respect to the three base leg pivot points at the ends of shafts 62. During

system calibration, a fixed displacement vector (from the origin of platform 30 coordinate frame) of the operator's wrist joint is estimated. Figure 4 shows the vector relationships between base 48 and platform 30 coordinate frames. Processor or control system 12, through force feedback control 16, returns three Euler angles and three linear translations from nominal platform 30 origin. Additionally, force and torque sensor 34 inputs are used in either position or rate mode to command a six degree of freedom velocity that motorized legs 36 and shaft drives 46 are to deliver. Thus, processor or control system 12 must first solve the geometric task of computing orientation and translation, and then compute the requisite leg or shaft rotational and linear velocities that result in the commanded and controller state.

Kinematic solutions to the hand grip platform Euler angles (defining attitude angles) and linear displacements from the center of the coordinate frame are obtained by use of nine potentiometers, 38 and 44. Fewer potentiometers can accomplish the same task of monitoring as the nine potentiometers. Telescoping legs or shafts 62 (whose links are actuator 36 driven) are attached to platform 30 by ball joints 32 and to base 48 by double-gimbaled motorized joints 60. Outer gimbals 60 are rigidly attached to base 48, are motor 52 driven, and cause a roll motion about the leg or shaft 62 motor axis of rotation. Outer gimbal 62 axis defines the leg or shaft 62 coordinate frame X-axis for each of the three legs or shafts 62. These three axes are each oriented along the radial directions with respect to the center of base 48. This results in the forward base 48 point having its motor axes along the X-axis of the base 48 coordinate frame. Azimuth angles ϕ_i to the other two base 48 points have constant values of 120 and 240 degrees, respectively. Inner gimbals 60 allow rotation about the respective leg or shaft 62 pitch axes. Designating the length of the three legs 62 d_i, where i equals 1, 2, 3, and is defined $0 < d_{imin} < d_i < d_{imax}$. Then the position vectors of platform 30 ball joints 32 with respect to base 48 frame S_B:

$$\vec{P}_i = E_i(\Psi_0) \cdot E(\theta_i, \phi_i) \cdot \begin{bmatrix} 0 \\ 0 \\ d_i \end{bmatrix} + \vec{P}_{Bi}; \quad i = 1, 2, 3 \qquad (1)$$

where

$$E(\theta_i, \phi_i) = \begin{bmatrix} \cos\theta_i & 0 & \sin\theta_i \\ \sin\theta_i \sin\phi_i & \cos\phi_i & -\cos\theta_i \sin\phi_i \\ -\sin\theta_i \sin\phi_i & \sin\phi_i & \cos\theta_i \cos\phi_i \end{bmatrix} \qquad (2)$$

and

$$E_i(\Psi_0) = \begin{bmatrix} \cos\Psi_0 & -\sin\Psi_0 & 0 \\ \sin\Psi_0 & \cos\Psi_0 & 0 \\ 0 & 0 & 1 \end{bmatrix}; \quad \Psi_0 = 0, 120, 240 \text{ deg for } i = 1, 2, 3 \qquad (3)$$

Processor of control system 12 is also a single board microcomputer as available under said type 68020 housed in a standard Motorola chassis having several analog-to-digital interface cards. Six tachometers 42 and 54 on three legs 62 measure motor speeds of leg-extending or retracting motors 40 and leg-angular rotating motors 52. There are two motors, 40 and 52, per leg 62. Linear potentiometers 38 measure leg 62 extension and two angular potentiometers 44 per leg 62 measure angles of each leg 62 relative to base 48. There is a total of nine potentiometers 38 and 44.

Rate and position control modes of hand controller 10 differ. In the position mode, removal of grip, force and torque commands from the operator causes hand controller 10 to remain at its latest attained attitude and linear displacement. Removal of input in the rate mode will cause a return of hand controller 10 to the initial displacement origin. Any of the

six degrees of freedom of hand controller 10 may be locked out as desired. Software stops are provided to prevent hand controller 10 from running into hard stops which might cause damage.

Figures 5a and 5b constitute an overview signal flow diagram of hand controller 10 input and motor control channels. Force/torque sensor 34 is a strain gauge type of sensor for detecting applied force and torque to hand grip 28 of controller 10. Interface 13 provides for keyboard or other type of input to the processor which includes input command processing 68 and motor command 70. Interface 13 is a RS-232 terminal interface for operator inputs of the controller 10 processor. Control system 66 provides for needed interaction among force and torque sensor 34, input command processing 68 and interface 13. Control system 66 includes sensor 34 electronics and control and may incorporate a Lord® preprocessor and a Lord® controller for sensor 34, from Assurance Technologies, Inc., of Garner, NC 27529. Controller function 72 incorporates software to perform the calculations of required motor rates to equal commanded input velocities of translation and rotation by incorporation kinematic system equations. Orientation function 74 incorporates software to perform the calculations of the platform and/or virtual pivot translation and rotation with respect to the base coordinate system. Inputs represent shaft or leg lengths, elevations and azimuth angles obtained from the nine potentiometers 38 and 44 (three per shaft or leg). Function 74 incorporates reverse kinematic system equations in its calculations. External object or device 18 receives input for external control and outputs signals for providing reflected force or torque (i.e., "feel" dynamics), or alarms.

The following describes the geometric relationships. Position vectors of the pivots are defined by $\bar{R}_{Bi}$ and $\bar{R}_{Pi}$, where i = 1, 2, 3, in the two separate frames S_B (the base 48 frame) and S_P (the platform 30 frame), results in

$$\bar{R}_{B1} = \begin{bmatrix} r_B \\ 0 \\ 0 \end{bmatrix}; \quad \bar{R}_{B2} = \begin{bmatrix} -r_B/2 \\ (\sqrt{3}/2)r_B \\ 0 \end{bmatrix}; \quad \bar{R}_{B3} = \begin{bmatrix} -r_B/2 \\ -(\sqrt{3}/2)r_B \\ 0 \end{bmatrix}$$

$$R_{P1} = \begin{bmatrix} r_P \\ 0 \\ 0 \end{bmatrix}; \quad R_{P2} = \begin{bmatrix} -r_P/2 \\ (\sqrt{3}/2)r_P \\ 0 \end{bmatrix}; \quad R_{P3} = \begin{bmatrix} -r_P/2 \\ -(\sqrt{3}/2)r_P \\ 0 \end{bmatrix}$$

$$\bar{R}_C = \frac{1}{3}\sum_{i=1}^{3}\left(\bar{R}_i + \bar{R}_{Bi}\right) = \frac{1}{3}\sum_{i=1}^{3}\bar{R}_i$$

since the sum $\Sigma\,\bar{R}_{Bi} = 0$.
or

$$\bar{R}_C = \frac{1}{3}\sum_{i=1}^{3} E_i\,(\Psi_0)\cdot\begin{bmatrix} -d_i \sin\theta_i \\ d_i \cos\theta_i \sin\phi_i \\ -d_i \cos\theta_i \cos\phi_i \end{bmatrix}$$

The above dot represents a matrix dot product. Referring to Figure 4, the platform 30 $\hat{X}_P$ unit vector is directed from the center toward P_i. The $\hat{Y}_P$ unit vector is parallel to the line from P_3 to P_2. Then,

$$\hat{X}_P = \left[\frac{1}{r_P}\right]\left[\bar{R}_1 - \bar{R}_C\right] = \left[\frac{2}{3}\bar{R}_1 - \frac{1}{3}(\bar{R}_2 + \bar{R}_3)\right]$$

$$\hat{Y}_P = \left[\frac{1}{\sqrt{3}\, r_P} \right] \left[\bar{R}_2 - \bar{R}_3 \right]$$

$$\hat{Z}_P = \hat{X}_P \times \hat{Y}_P = \left[\frac{2\sqrt{3}}{9r^2_P} \right] \left[\bar{R}_1 \times \bar{R}_2 + \bar{R}_2 \times \bar{R}_3 + \bar{R}_3 \times \bar{R}_1 \right]$$

The direction cosines of the $\hat{X}_P$, $\hat{Y}_P$, and $\hat{Z}_P$ unit vectors are the components of the preceding vector equations. The Euler rotation matrix from S_B to S_P is then

$$E_{P/B} = \begin{bmatrix} \hat{X}_P \cdot \hat{X}_B & \hat{Y}_P \cdot \hat{X}_B & \hat{Z}_P \cdot \hat{X}_B \\ \hat{X}_P \cdot \hat{Y}_P & \hat{Y}_P \cdot \hat{Y}_B & \hat{Z}_P \cdot \hat{Y}_B \\ \hat{X}_P \cdot \hat{Z}_B & \hat{Y}_P \cdot \hat{Z}_B & \hat{Z}_P \cdot \hat{Z}_B \end{bmatrix} = \left\{ e_{ij} \right\}.$$

The above dots represent vector dot products.

All information concerning the relative attitude orientation between the base 48 and platform 30 frames is contained in the Euler matrix $E_{P/B}$. Euler angles can be defined in 24 different ways depending on the sequence of rotations (in a positive sense about each of three axes). There are 12 permutations starting with either frame S_P or S_B, or 24 total. Each set of three angles is not interchangeable (except for very small rotations). Each set does, however, result in the same rotation of one frame to another when applied in its specific sequence.

The following set arises from a yaw rotation about the S_B z axis followed by a pitch rotation bout the y axis and a final roll about the x axis:

$$\Psi_P = \tan^{-1}({}^e12/{}^e11) = \text{Yaw}$$

$$\theta_P = \sin^{-1}({}^{-e}13) = \text{Pitch}$$

$$\phi_P = \tan^{-1}({}^e23/{}^e33) = \text{Roll}$$

Each rotation assumes the right-hand rule for positive sense. The inverse transformation performs a roll-pitch-yaw transformation (in that order) which is not uncommon in the aircraft industry.

The following describes the platform velocity equations. Tachometers 42 and 54 mounted on the handcontroller 10 legs and roll axis shafts are used in a velocity feedback controller 16 that drives each motorized leg 62 to null a separate commanded velocity. These six velocities are in turn computed according to the six signals from force/torque sensor 34 (after biasing to provide reflected force or torque dynamics for the operator).

At present, handgrip 28 force signals are interpreted as referenced to the base 48 coordinate frame as a linear velocity command. The coordinate system used is arbitrary and can be easily redefined in processor code and provided as an optional handcontroller 10 operating mode at a later time if desired.

The inertial velocity $\bar{V}_i$ of each leg 62 is composed of the linear velocity of the platform 30 center summed with the rotational velocity about the center, that is

$$\vec{V}_i = \frac{d}{dt} \vec{R}_i = E_i\ (\Psi_0) \left\{ \frac{d}{dt} \left[E_i(r_i,\ d_i) \cdot \begin{bmatrix} 0 \\ 0 \\ -d_i \end{bmatrix} \right] \right\}$$

$$= \vec{V}_C + \vec{\omega}_P\ (\vec{R}_i - \vec{R}_C);\ i = 1,\ 2,\ 3$$

$$\vec{V_i} = \Omega_i\ (\Psi_0,\ \theta_i,\ \phi_i,\ d_i) \cdot \begin{bmatrix} \dot{\theta}_i \\ \dot{\phi}_i \\ \dot{d}_i \end{bmatrix} = \vec{V_C} + \vec{\omega_P}\ (\vec{R_i} - \vec{R_C});$$

$$i = 1,\ 2,\ 3$$

where $\dot{\theta}_i$, $\dot{\phi}_i$, and $\dot{d}_i$ are the time rate of change of angles θ_i ϕ_i, and leg length d_i for each leg. Then,

$$\begin{bmatrix} \dot{\theta}_i \\ \dot{\phi}_i \\ \dot{d}_i \end{bmatrix} = \Omega_i^{-1}\ [\vec{V_C} + \vec{\omega_P}\ (\vec{R_i} - \vec{R_C})];\ i = 1,\ 2,\ 3$$

In the above equation, only the expressions for leg roll and length rates are of interest as the handcontroller 10 leg 62 pitching rates are automatically driven by mechanical constraints. This solution requires inversion of a 3 by 3 matrix, where

$$\Omega_i\ (\Psi_0,\ \theta_i,\ \phi_i,\ d_i) =$$

$$E_i(\Psi_0) \cdot \begin{bmatrix} 0 & -d_i\ \cos\theta_i & -\sin\theta_i \\ d_i\ \cos\theta_i\ \cos\phi_i & -d_i\ \sin\theta_i\ \sin\phi_i & \cos\theta_i\ \sin\phi_i \\ d_i\ \cos\theta_i\ \sin\phi_i & d_i\ \sin\theta_i\ \cos\phi_i & -\cos\theta_i\ \cos\phi_i \end{bmatrix};$$

$$i = 1,\ 2,\ 3$$

The platform 30 angular velocity vector input commands, ωp, above are referenced to S_B; if they are instead referenced to S_P, they are simply converted by the inverse Euler transformation as follows:

$$\omega_P = \begin{bmatrix} \omega_X \\ \omega_Y \\ \omega_Z \end{bmatrix}_B = E^{-1}{}_{P/B} \begin{bmatrix} \omega_{Xc} \\ \omega_{Yc} \\ \omega_{Zc} \end{bmatrix}_P$$

The inverse Euler matrix is the transpose of the matrix since the coordinate frame is orthogonal and Cartesian.

In summary, one feature of hand controller 10 is that the sensed location of the pivot point can be set arbitrarily. It can be set through the center of grip 28, above or below it, or be centered inside the operator's wrist. For example, with a pivot point below grip 28, it would act like a conventional military aircraft hand controller having the pivot point where the control stick attaches to the floor or deck of the aircraft. However, with the pivot point above grip 28, the top of the grip would be seemingly attached to a point above it and the grip would swing freely below it. The programmability of the pivot point provides for maximum flexibility and adaptability of hand controller 10. These changes in location of pivot point can be made by entering the appropriate software commands in control system 12. An initial setting can be made by the operator through the movement of his or her wrist for setting the virtual pivot and control swing and rotation

dimensions in accordance with and to match the wrist movement. Other operating characteristics can be changed simply by altering the software. Such things as break out forces, the degree of freedom available, damping rates, spring tensions and velocity rates can be modified without altering the hardware of control system 12 or hand controller 10. Based on information from the vehicle or object being controlled, the operator is given feedback through grip 28. This capability is force reflection and usually involves providing tactile feedback through grip 20 when the control object 18 (e.g., a robot arm or vehicle) contacts the target or other object. The combination of a programmable virtual pivot point having an active hand controller 10 allows the operator or user to configure hand controller 10 to match or meet the demands or needs of a particular task and user.

Motor-driven force feedback (microprocessor 12 control) replaces spring centering. Gradients of forces or torques versus displacements (in each of six axes), as shown in Figure 2, are stored as parameters that can be modified by keyboard 13 input. Such modification provides adaptability or programmability of key hand controller 10 operating characteristics including sensed (virtual) pivot axes locations and range of motion in each axis, sensed spring force reflection or the feel of grip 28 (i.e., force/displacement gradients), the capability, as desired, to implement bilateral force feedback from system 18 being controlled (via motor control feedback) to the human operator and the capability of operator-mode control to introduce menu-driven commands (via the VMEbus single-board computer).

Claims

1. A six degree-of-freedom virtual pivot hand controller (10) comprising:

   - grip means (28) for receiving externally applied force and torque;
   - force and torque sensing means (34) connected to said grip means for sensing the force and torque from up to six degrees-of-freedom applied to said grip means;
   - first support means (30) connected to said sensing means for supporting said sensing means;
   - second support means (48) for supporting said hand controller (10);
   - at least one variable-length member means (62) having a first flexible connector (32) attached to said first support means (30) and a second flexible connector (60) attached to said second support means (48) for variable supporting said first support means, wherein
   - said at least one variable-length member means (62) comprises:

     -- translation actuating means (36, 40) connected to said member means (62) for varying the length of said member means,
     -- translational sensing means (38) connected to said member means (62) for sensing a length of said member means,
     -- angular actuating means (46, 50, 52) connected to said member means (62) for angularly moving said member means (62) relative to said second support means, and
     -- angular sensing means (44) connected to said member means (62) for sensing an angular position of said member means (62) relative to said second support means.

2. Controller according to claim 1,

   characterized by comprising processing and control means (12) connected to said force and torque sensing means (34), to said translational sensing means (38), to said angular sensing means (44), to said translational actuating means (36, 40) and to said angular actuating means (46, 50, 52), for receiving signals from said force and torque sensing means, said translational sensing means and said angular sensing means, and for sending signals to said translational actuating means and to said angular actuating means.

3. Controller according to claim 2,

   characterized in that said processing and control means (12) sends signals to an external device (18) to be controlled by said hand controller (10), and receives signals for the external device.

4. Controller according to claim 3, **characterized in that** a spring-like reflective force and torque is produced whereby any externally applied force and torque to said grip means (28) is sensed by said force and torque sensing means (34) which in turn sends signals indicating force and torque to said processing and control means (12) which in turn sends signals indicating certain kinds of control to the external device (18) being controlled which in turn sends signals of action and reflective force of the external device to said processing and control means which in turn sends

signals of reflective force and movement to said translational actuating means and to said angular actuating means which in turn provide reflective force, torque and movement in response to the any externally applied force and torque to said grip means.

5. Controller according to claim 4, **characterized in that** said grip means (28) reflects a virtual pivot point due to the spring-like reflective force and torque, and a movement due to the any externally applied force and torque.

6. Controller according to claim 4,

   characterized in that
   a location of the virtual pivot point and magnitudes of the spring-like reflective force and torque and of movement may be varied via input information to said processing and control means (12).

7. Controller according to claim 1,

   characterized in that

   - said first flexible connector is a ball joint (32);
   - said second flexible connector is a universal joint (60);
   - said translation actuating means comprises a first motor (40) connected to said interface and control means (12) for drawing said actuating means which changes length of said variable-length member means (62);
   - said translational sensing means comprises: a first tachometer (42) connected to the first motor and to said interface and control means, and a linear potentiometer (38) connected to said linear actuator and to said interface and control means;
   - said angular actuating means further comprises a second motor (52) connected to said interface and control means for driving said angular actuating means; and
   - said angular sensing means comprises:

     -- a first angular potentiometer (44) connected to said universal joint and to said interface and control means,
     -- a second angular potentiometer (44) connected to said universal joint and to said interface and control means, and
     -- a second tachometer (54) connected to the second motor (52) and to said interface and control means.

Patentansprüche

1. Steuerknüppel mit virtuellem Gelenk und sechs Freiheitsgraden, aufweisend:

   - eine Griffvorrichtung (28) zur Aufnahme einer extern angelegten Kraft und eines Drehmomentes;
   - eine Kraft- und Drehmomentsensoreinrichtung (34), die mit der Griffvorrichtung verbunden ist, um die Kraft und das Drehmoment von bis zu sechs Freiheitsgraden zu erfassen, die an die Griffvorrichtung angelegt werden;
   - eine erste Abstützvorrichtung (30), die mit der Erfassungseinrichtung verbunden ist, um diese abzustützen;
   - eine zweite Abstützvorrichtung (48) zur Abstützung des Steuerknüppels (10);
   - wenigstens ein Element (62) mit variabler Länge und mit einem ersten flexiblen Verbindungsglied (32), das mit der ersten Abstützvorrichtung (30) verbunden ist und einem zweiten flexiblen Verbindungsglied (60), das mit der zweiten Abstützvorrichtung (48) verbunden ist, um die erste Abstützvorrichtung variabel abzustützen, wobei
   - das wenigstens ein Element (62) mit variabler Länge umfaßt:

     -- eine Translations-Betätigungseinrichtung (36, 40), die mit dem Element (62) verbunden ist, um die Länge des Elements zu verändern,
     -- eine Translations-Sensoreinrichtung (38), die mit dem Element (62) verbunden ist, um eine Länge des Elementes zu erfassen,
     -- eine Winkel-Betätigungseinrichtung (48, 50, 52), die mit dem Element (62) verbunden ist, um winkelmäßig das Element (62) relativ zu der zweiten Abstützvorrichtung zu bewegen, und
     -- eine Winkel-Sensoreinrichtung (44), die mit dem Element (62) verbunden ist, um eine Winkelposition des Elements (62) relativ zu der zweiten Abstützvorrichtung zu erfassen.

2. Steuerknüppel nach Anspruch 1, **gekennzeichnet durch** eine Verarbeitungs- und Steuereinrichtung (12), die mit

der Kraft- und Drehmoment-Sensoreinrichtung (34), der Translations-Sensoreinrichtung (38), der Winkel-Sensoreinrichtung (44), der Translations-Betätigungseinrichtung (36, 40) und der Winkel-Betätigungseinrichtung (46, 50, 52) verbunden ist, um Signale von der Kraft- und Drehmomentsensoreinrichtung, der Translations-Sensoreinrichtung und der Winkel-Sensoreinrichtung zu empfangen und um Signale zu der Translations-Betätigungseinrichtung und der Winkel-Betätigungseinrichtung zu senden.

3. Steuerknüppel nach Anspruch 2, **dadurch gekennzeichnet**, daß die Verarbeitungs- und Steuereinrichtung (12) Signale zu einer externen Einrichtung (18) sendet, die durch den Steuerknüppel (10) zu steuern ist und Signale für die externe Einrichtung empfängt.

4. Steuerknüppel nach Anspruch 3, **dadurch gekennzeichnet**, daß eine federähnliche Reflexionskraft und ein Drehmoment erzeugt wird, wobei jede extern an die Griffvorrichtung (28) angelegte Kraft und Drehmoment durch die Kraft- und Drehmoment-Sensoreinrichtung (34) erfaßt wird, welche ihrerseits Signale sendet, die die Kraft und das Drehmoment der Verarbeitungs- und Steuereinrichtung (12) anzeigen, welche ihrerseits Signale sendet, die bestimmte Arten der Steuerung der extern gesteuerten Einrichtung (18) anzeigen, welche ihrerseits Signale der Aktion und der reflektiven Kraft der externen Einrichtung zu der Verarbeitungs- und Steuereinrichtung sendet, welche ihrerseits Signale der reflektiven Kraft und der Bewegung zu der Translations-Betätigungseinrichtung und der Winkel-Betätigungseinrichtung sendet, welche ihrerseits eine reflektive Kraft, ein Drehmoment und eine Bewegung aufgrund einer extern angelegten Kraft und eines Drehmomentes der Griffvorrichtung vorgibt.

5. Steuerknüppel nach Anspruch 4, **dadurch gekennzeichnet**, daß die Griffvorrichtung (28) einen virtuellen Gelenkpunkt aufgrund der federähnlichen reflektiven Kraft und des Drehmomentes und einer Bewegung infolge einer extern angelegten Kraft und eines Drehmomentes wiedergibt.

6. Steuerknüppel nach Anspruch 4, **dadurch gekennzeichnet**, daß ein Ort des virtuellen Gelenkpunktes und die Größe der federähnlichen reflektiven Kraft und des Drehmomentes und der Bewegung über Eingangsinformation zu der Verarbeitungs- und Steuereinrichtung (12) variiert werden können.

7. Steuerknüppel nach Anspruch 1, **dadurch gekennzeichnet**, daß

- die erste flexible Verbindung ein Kugelgelenk (32) ist;
- die zweite flexible Verbindung ein Universalgelenk (60) ist;
- die Translations-Betätigungseinrichtung einen ersten Motor (40) umfaßt, der an die Schnittstellen- und Steuereinrichtung (12) angeschlossen ist, um die Betätigungseinrichtung auseinander zu ziehen, welche die Länge des Elements (62) mit variabler Länge variiert;
- die Translations-Sensoreinrichtung umfaßt:
- ein erstes mit dem ersten Motor und der Schnittstellen- und Steuereinrichtung verbundenes Tachometer (42) und ein mit dem linearen Betätiger und der Schnittstellen- und Steuereinrichtung verbundenes Linear-Potentiometer (38);
- die Winkel-Betätigungseinrichtung ferner einen zweiten Motor (52) umfaßt, der an die Schnittstellen- und Steuereinrichtung angeschlossen ist, um die Winkel-Betätigungseinrichtung zu steuern; und
- die Winkel-Sensoreinrichtung umfaßt:
    - -- ein erstes Winkel-Potentiometer (44), das mit dem Universalgelenk und der Schnittstellen- und Steuereinrichtung verbunden ist,
    - -- ein zweites Winkel-Potentiometer (44), das mit dem Universalgelenk und der Schnittstellen- und Steuereinrichtung verbunden ist, und
    - -- ein zweites Tachometer (54), das mit dem zweiten Motor (52) und der Schnittstellen- und Steuereinrichtung verbunden ist.

Revendications

1. Dispositif de commande à main à pivot virtuel à six degrés de liberté (10) comprenant:

- un moyen formant poignée (28) destiné à recevoir une force et un couple appliqués de l'extérieur;
- un moyen de détection de force et de couple (34), relié audit moyen formant poignée, pour détecter la force et le couple provenant de jusqu'à six degrés de liberté, appliqués audit moyen formant poignée,

- un premier moyen de support (30), relié audit moyen de détection, pour supporter ledit moyen de détection,
- un second moyen de support (48) destiné à supporter ledit dispositif de commande à main (10),
- au moins un moyen formant un élément de longueur variable (62), qui comporte un premier raccord flexible (32) fixé audit premier moyen de support (30) et un second raccord flexible (60) fixé audit second moyen de support (48) afin de supporter de façon variable ledit premier moyen de support, dans lequel
- ledit ou lesdits moyen(s) formant élément de longueur variable (62) comprend ou comprennent:

  - un moyen d'actionnement en translation (36, 40) relié audit moyen formant élément (62), pour faire varier la longueur dudit moyen formant élément,
  - un moyen de détection de translation (38) relié audit moyen formant élément (62), pour détecter une longueur dudit moyen formant élément,
  - un moyen d'actionnement angulaire (46, 50, 52) relié audit moyen formant élément (62), pour assurer un déplacement angulaire dudit moyen formant élément (62) par rapport audit second moyen de support, et
  - un moyen de détection d'angle (44) relié audit moyen formant élément (62), pour détecter une position angulaire dudit moyen formant élément (62) par rapport audit second moyen de support.

2. Dispositif de commande selon la revendication 1, caractérisé en ce qu'il comprend un moyen de traitement et de commande (12) relié audit moyen de détection de force et de couple (34), audit moyen de détection de translation (38), audit moyen de détection d'angle (44), audit moyen d'actionnement en translation (36, 40) et audit moyen d'actionnement angulaire (46, 50, 52), pour recevoir des signaux provenant dudit moyen de détection de force et de couple, dudit moyen de détection de translation et dudit moyen de détection d'angle, et pour envoyer des signaux audit moyen d'actionnement en translation et audit moyen d'actionnement angulaire.

3. Dispositif de commande selon la revendication 2,

caractérisé en ce que ledit moyen de traitement et de commande (12) envoie des signaux à un dispositif externe (18) devant être commandé par ledit dispositif de commande à main (10), et reçoit des signaux destinés au dispositif externe.

4. Dispositif de commande selon la revendication 3, caractérisé en ce qu'une force et un couple de réaction analogues à ceux d'un ressort sont produits, et toute force et tout couple quelconques, appliqués de l'extérieur audit moyen formant poignée (28), sont alors détectés par ledit moyen de détection de force et de couple (34), qui, à son tour, envoie des signaux indicatifs de la force et du couple audit moyen de traitement et de commande (12), lequel, à son tour, envoie des signaux indicatifs de certains types de commande au dispositif externe (18) commandé qui, à son tour, envoie des signaux d'action et de force de réaction du dispositif externe audit moyen de traitement et de commande, lequel, à son tour, envoie des signaux de force et de mouvement de réaction audit moyen d'actionnement en translation et audit moyen d'actionnement angulaire, qui, à leur tour, fournissent une force, un couple et un mouvement de réaction, en réponse à la force et au couple quelconques appliqués de l'extérieur audit moyen formant poignée.

5. Dispositif de commande selon la revendication 4, caractérisé en ce que ledit moyen formant poignée (28) simule un point-pivot virtuel sous l'effet de la force et du couple de réaction analogues à ceux d'un ressort, et un mouvement sous l'effet de la force et du couple quelconques appliqués de l'extérieur.

6. Dispositif de commande selon la revendication 4,

caractérisé en ce que
un emplacement du point-pivot virtuel et les amplitudes de la force et du couple de réaction, analogues à ceux d'un ressort, et du mouvement, peuvent être modifiés par l'intermédiaire d'une saisie d'informations au niveau dudit moyen de traitement et de commande (12).

7. Dispositif de commande selon la revendication 1,

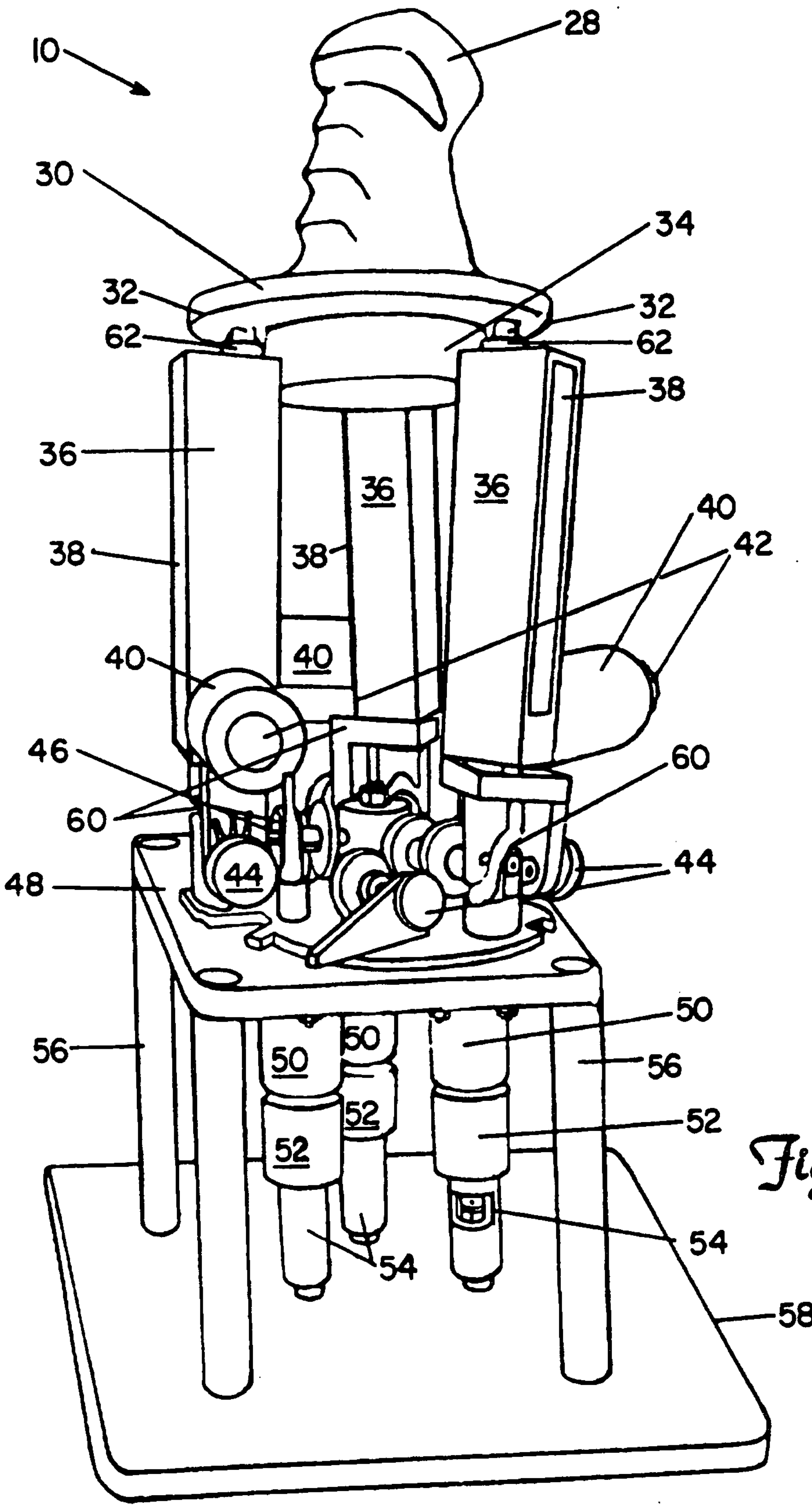
caractérisé en ce que

- ledit premier raccord flexible est un joint à rotule (32),
- ledit second raccord flexible est un joint universel (60),
- ledit moyen d'actionnement en translation comprend un premier moteur (40) relié audit moyen d'interface et

de commande (12) afin de tirer ledit moyen d'actionnement, lequel modifie la longueur dudit moyen formant élément de longueur variable (62),

- ledit moyen de détection de translation comprend:
  un premier tachymètre (42) relié au premier moteur et audit moyen d'interface et de commande, et un potentiomètre linéaire (38) relié audit actionneur linéaire et audit moyen d'interface et de commande,
- ledit moyen d'actionnement angulaire comprend, en outre, un second moteur (52) relié audit moyen d'interface et de commande afin d'entraîner ledit moyen d'actionnement angulaire, et
- ledit moyen de détection d'angle comprend:

  - un premier potentiomètre angulaire (44) relié audit joint universel et audit moyen d'interface et de commande,
  - un second potentiomètre angulaire (44) relié audit joint universel et audit moyen d'interface et de commande, et
  - un second tachymètre (54) relié au second moteur (52) et audit moyen d'interface et de commande.


10
28
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34
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58

Fig. 1

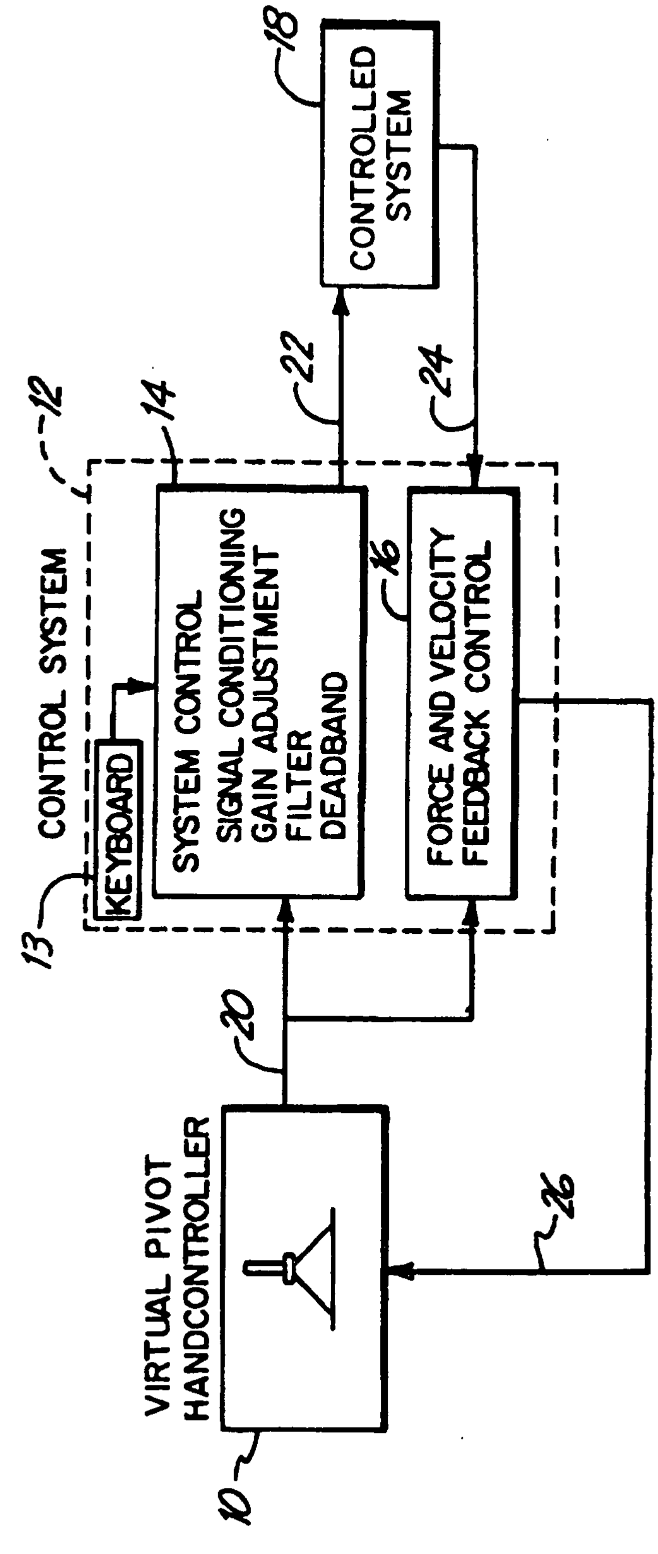

CONTROL SYSTEM
12
13
KEYBOARD
14
SYSTEM CONTROL
SIGNAL CONDITIONING
GAIN ADJUSTMENT
FILTER
DEADBAND
16
FORCE AND VELOCITY
FEEDBACK CONTROL
18
CONTROLLED
SYSTEM
22
24
20
26
10
VIRTUAL PIVOT
HANDCONTROLLER

Fig. 2

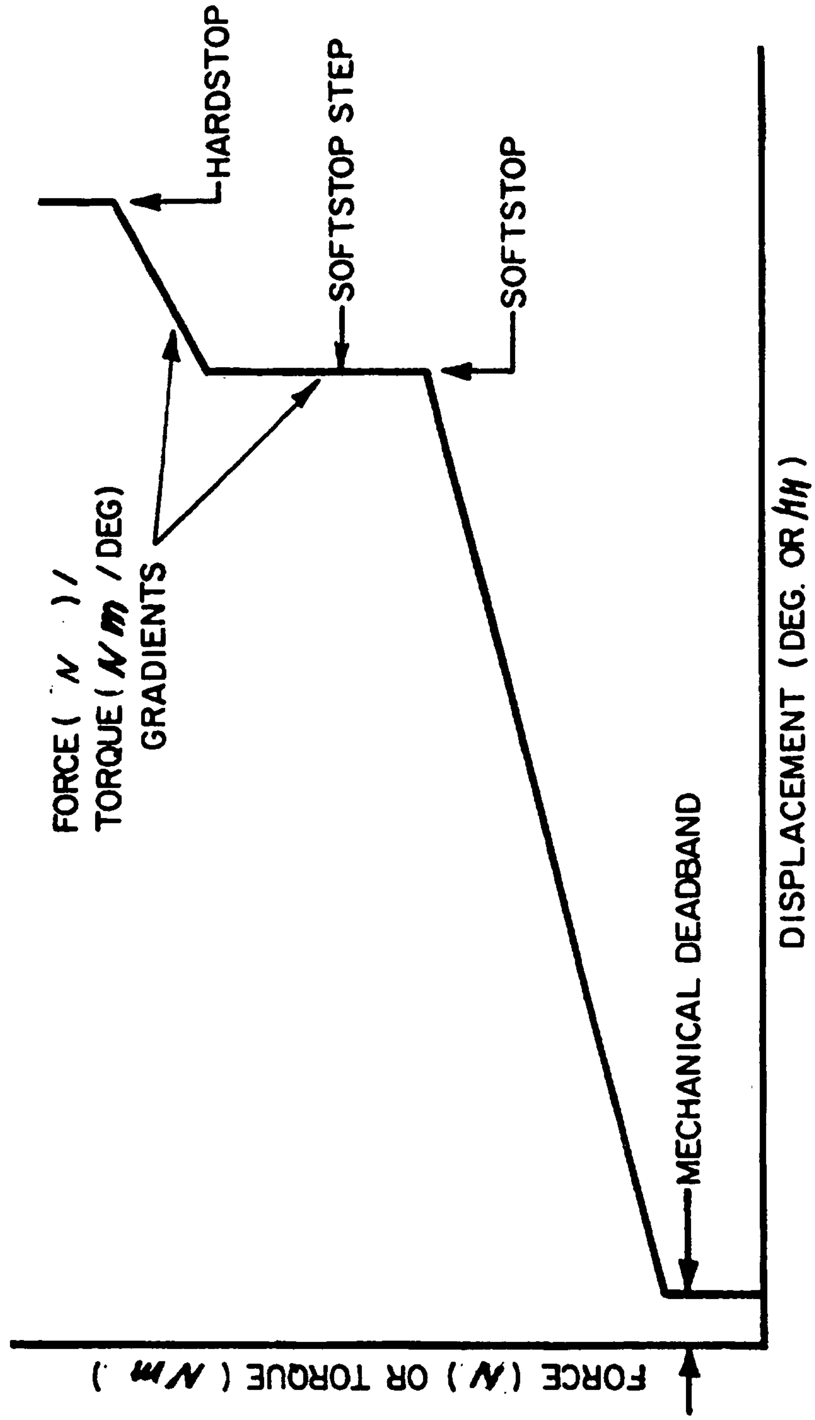

HARDSTOP
SOFTSTOP STEP
SOFTSTOP
FORCE (N)/
TORQUE (Nm/DEG)
GRADIENTS
MECHANICAL DEADBAND
DISPLACEMENT (DEG. OR MM)
FORCE (N) OR TORQUE (Nm)

Fig. 3

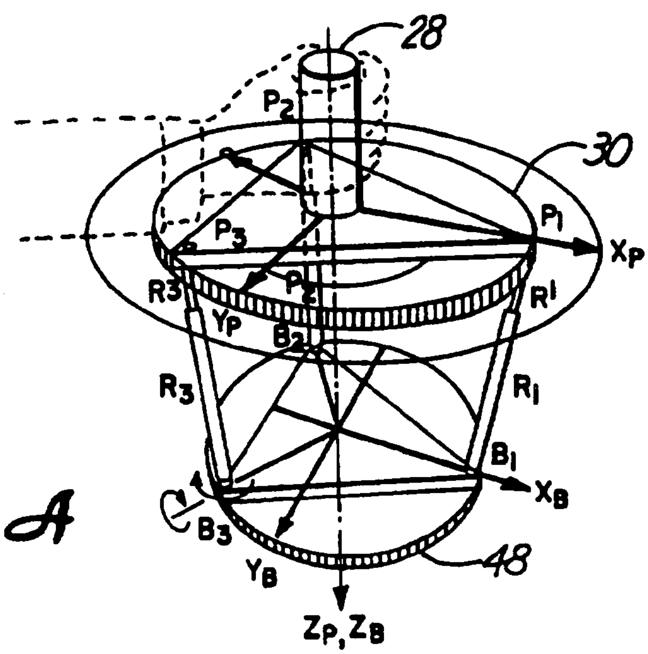


Fig. 4A

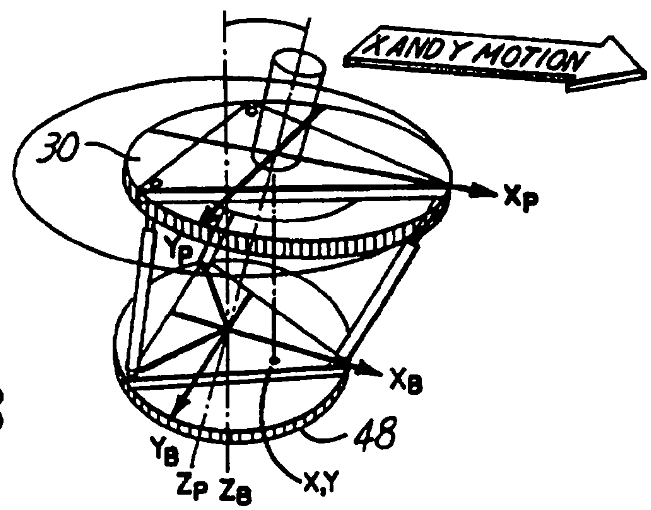


Fig. 4B

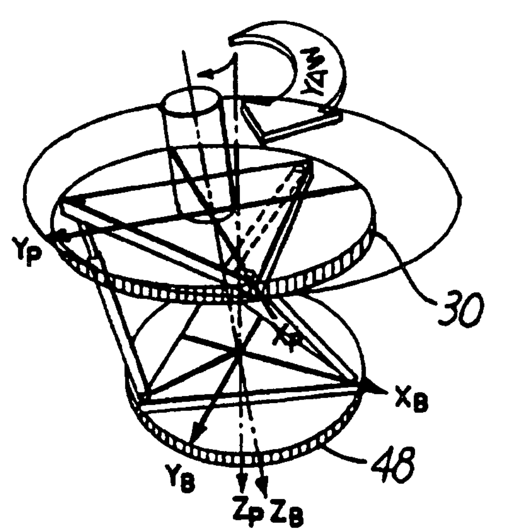


Fig. 4C

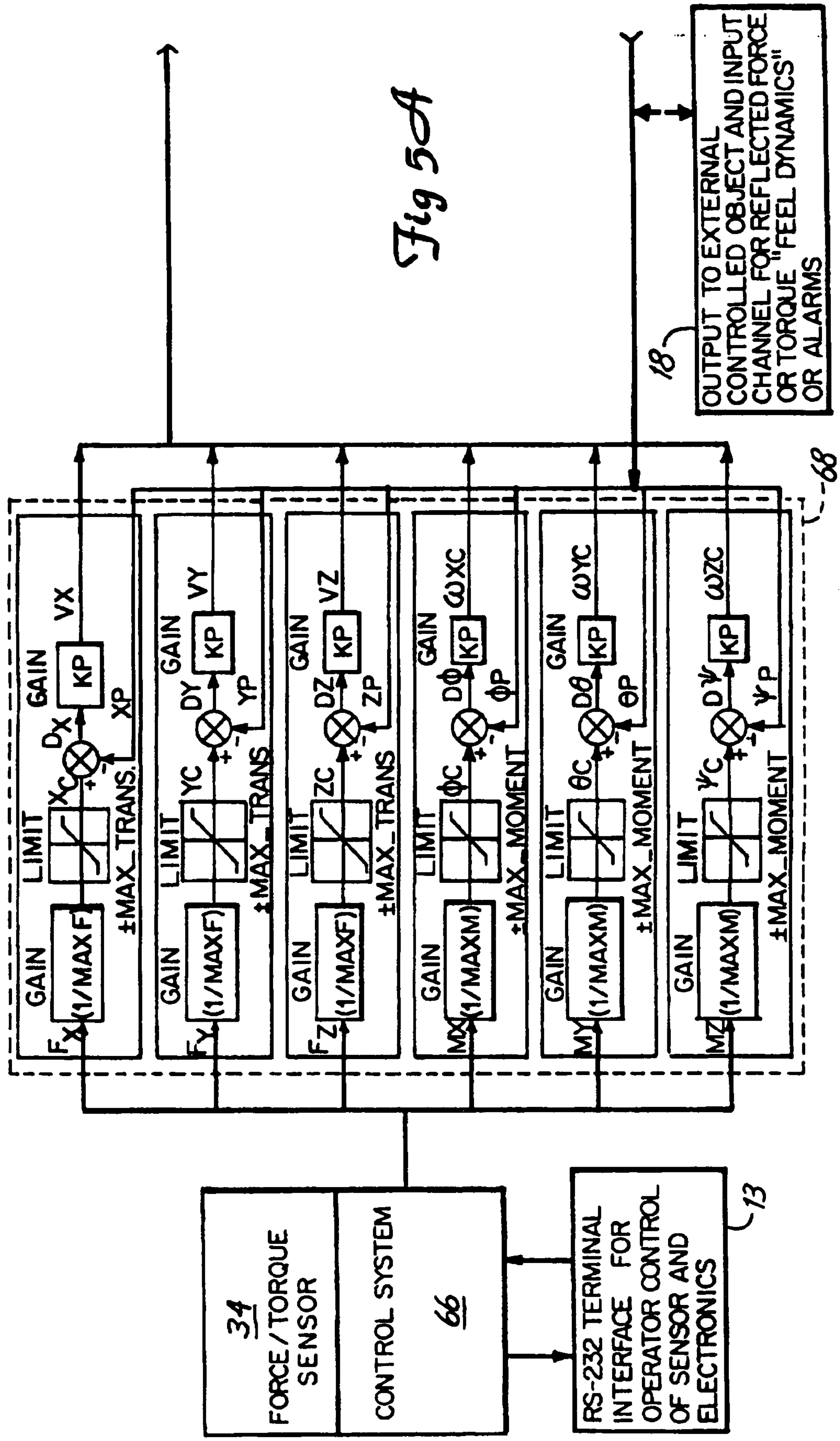

OUTPUT TO EXTERNAL CONTROLLED OBJECT AND INPUT CHANNEL FOR REFLECTED FORCE OR TORQUE "FEEL DYNAMICS" OR ALARMS
18
68
GAIN
(1/MAXF)
(1/MAXM)
LIMIT
±MAX_TRANS
±MAX_MOMENT
KP
VX
VY
VZ
ωXC
ωYC
ωZC
34
FORCE / TORQUE SENSOR
CONTROL SYSTEM
66
RS-232 TERMINAL INTERFACE FOR OPERATOR CONTROL OF SENSOR AND ELECTRONICS
13

Fig 5A

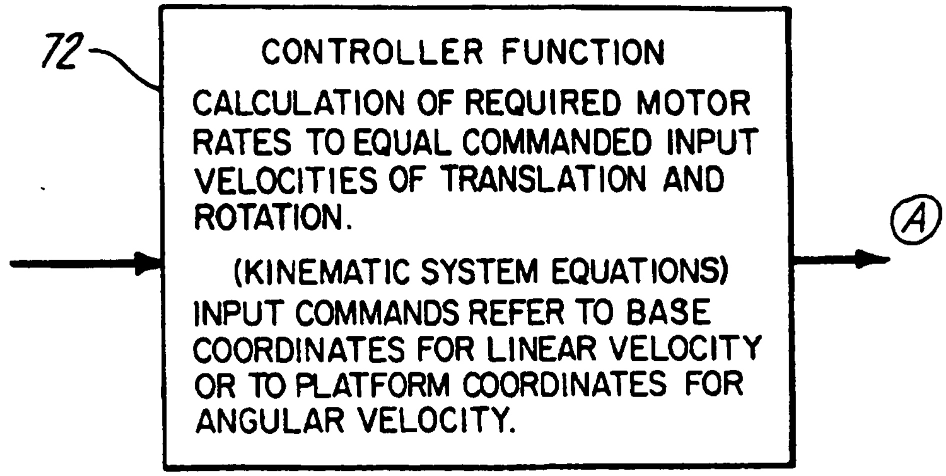
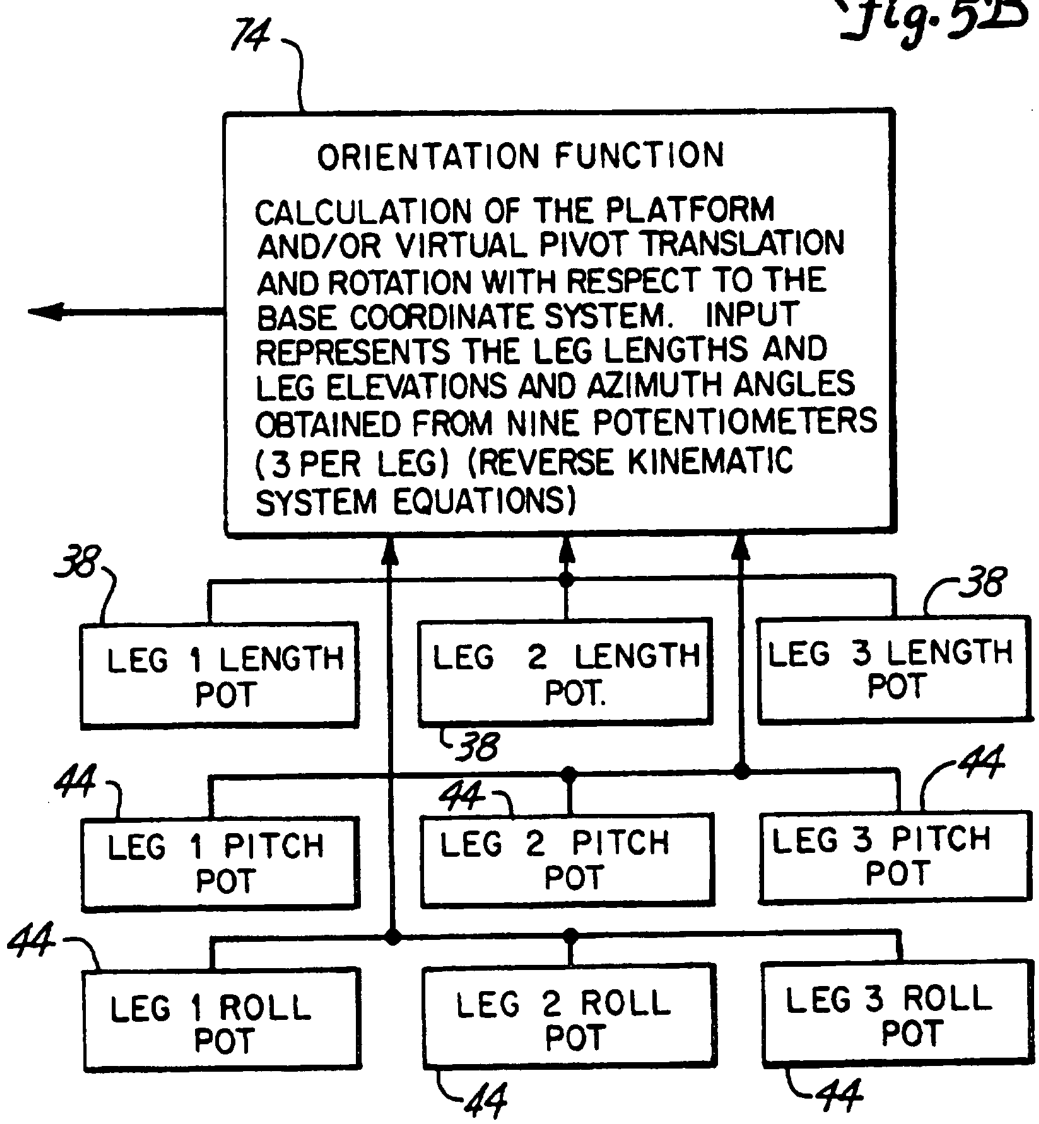

72
CONTROLLER FUNCTION
CALCULATION OF REQUIRED MOTOR RATES TO EQUAL COMMANDED INPUT VELOCITIES OF TRANSLATION AND ROTATION.
(KINEMATIC SYSTEM EQUATIONS)
INPUT COMMANDS REFER TO BASE COORDINATES FOR LINEAR VELOCITY OR TO PLATFORM COORDINATES FOR ANGULAR VELOCITY.
A

Fig. 5B


74
ORIENTATION FUNCTION
CALCULATION OF THE PLATFORM AND/OR VIRTUAL PIVOT TRANSLATION AND ROTATION WITH RESPECT TO THE BASE COORDINATE SYSTEM. INPUT REPRESENTS THE LEG LENGTHS AND LEG ELEVATIONS AND AZIMUTH ANGLES OBTAINED FROM NINE POTENTIOMETERS (3 PER LEG) (REVERSE KINEMATIC SYSTEM EQUATIONS)
38
LEG 1 LENGTH POT
LEG 2 LENGTH POT.
LEG 3 LENGTH POT
38
38
44
LEG 1 PITCH POT
44
LEG 2 PITCH POT
LEG 3 PITCH POT
44
44
LEG 1 ROLL POT
LEG 2 ROLL POT
LEG 3 ROLL POT
44
44

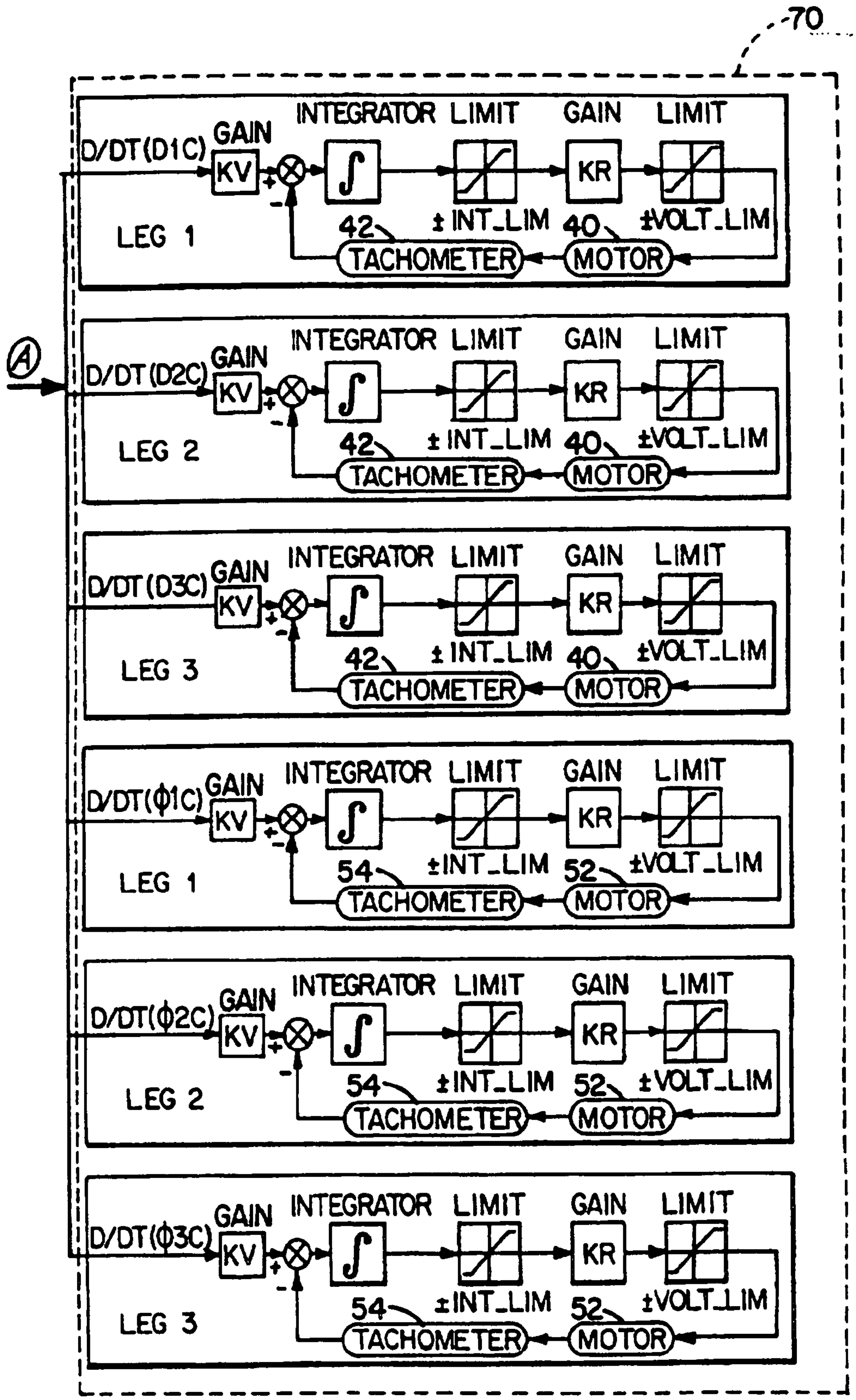

70
A
D/DT(D1C)
GAIN
KV
INTEGRATOR
LIMIT
GAIN
KR
LIMIT
± INT_LIM
±VOLT_LIM
LEG 1
42
TACHOMETER
40
MOTOR
D/DT(D2C)
LEG 2
D/DT(D3C)
LEG 3
D/DT(φ1C)
LEG 1
54
52
D/DT(φ2C)
LEG 2
D/DT(φ3C)
LEG 3

Fig. 5C